Fact Sheet: A Scientific Roadmap for Making Cellulosic Ethanol a Practical Alternative to Gasoline

The Department of Energy (DOE)* has issued a roadmap (July 2006) for new biomass to biofuels research. The report, *Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda*, and this fact sheet may be viewed at www.doegenomestolife.org/biofuels/. The new research roadmap aims to accelerate the development of technological breakthroughs needed to efficiently produce cellulosic ethanol. The plan leverages revolutionary advances made in genomics research and computation to build the new scientific and practical foundation needed to support an economic and sustainable biofuel industry.

Cellulosic Ethanol: An Abundant, Secure Energy Source for a Cleaner Environment

Cellulose-based ethanol is derived from the fibrous, generally inedible portions of plant matter (biomass) and offers a renewable, sustainable, and expandable resource to meet the growing demand for transportation fuel. It can be used in today's vehicles and distributed through the existing transportation-fuel infrastructure with only modest modifications. Additionally, the amount of carbon dioxide emitted to the atmosphere from producing and burning ethanol is far less than that released from gasoline.

Cellulosic ethanol is made by breaking apart the cellulose in plant cell walls into its component sugar molecules, which are then converted by microbes to ethanol. Cellulose is the most abundant biological material on earth and has the potential to help us meet and even exceed national energy goals. A 2005 joint DOE-USDA study concluded that the United States could theoretically produce over one billion dry tons of biomass each year, enough to generate at least 60 billion gallons of fuel ethanol.

The biomass crops used to make cellulosic ethanol (e.g., post-harvest corn plants and switchgrass) can be grown in every state and often on marginal lands. They are supportable within the current agricultural infrastructure, making them available to contribute to our energy security.

The National Goal: Displacing 30% of Gasoline by 2030

Secretary of Energy Samuel Bodman recently announced the goal of making ethanol a practical and cost-competitive alternative by 2012 (at $1.07/gal) and displacing 30% (60 billion gallons) of gasoline by 2030. The United States now produces 4.5 billion gallons of (corn-grain) ethanol per year, a fraction of the 140 billion gallons of transportation fuel used annually.

Although most of the ethanol produced today is derived from corn grain, dramatic increases in the availability of ethanol are expected through increases in quantity and decreases in cost of ethanol from biomass. Corn-based ethanol is helping the new cellulosic ethanol industry by providing technology improvements, infrastructure, and demand. Both corn and cellulosic-based ethanol are likely to assist each other's growth.

The Doe Research Plan

The roadmap identifies biotechnology breakthroughs that have the potential to increase the national biomass supply many fold:

- Biomass crops will be bred to increase the quantity of biomass per acre, grow better on marginal lands, be more drought- and pest-tolerant, and be less costly to harvest.
- Biotechnology may lead to the breeding of biomass crops with characteristics that make them more easily converted to ethanol, such as the substitution of cellulose, which is easy to convert, for lignin, which is difficult to convert.

Research is also described that will facilitate converting cellulosic material to ethanol in biorefineries:

- Current processes usually involve several separate steps, such as the separation and individualized treatment of intermediate products. Future processes could combine multiple steps, saving capital investments and reducing operating costs.
- Many current processes rely on chemical treatment; future options are more likely to be based on biology, that may reduce cost and reduce waste byproducts.

The research agenda set forth in this roadmap will involve broad coordination across DOE and other federal agencies, while relying upon the skills of the scientific and industrial community.

The Challenges: Achieving Higher Volume, Greater Efficiency

Scientists believe that biotechnological advances will enable, in some cases, the doubling or more of the current yield of biomass. Relatively little research has been conducted to increase biomass productivity so far; indeed, most plant research has focused on improving the edible portions of crops.

New biotechnology tools can avoid the usually lengthy period needed to grow a plant from a seed to identify new characteristics. Instead, the new tools can rapidly improve crop characteristics by identifying the desired responses at the molecular level and testing genetic traits using high-throughput molecular analysis.

The sugars required for fermentation to ethanol are locked in a complex package encased by plant cell walls that naturally resist biological and chemical degradation—one of the reasons wood is used as a construction material.

Thus, an understanding of cell wall structure and function—how it is synthesized into complex chains (polymers) of sugars to resist degradation, and also how microbes and fungi naturally deconstruct the polymers into simple sugars—is key to enhancing these crops and their processing and conversion into liquid fuels.

In addition to understanding and optimizing current crops, innovative energy crops—plants specifically designed for industrial processing to biofuels—may be developed concurrently with new biorefinery treatment and conversion processes.

Greater efficiencies must be achieved in processing sugars to ethanol. Improvements include streamlining many of the disparate steps—such as mixing, separating, cooling, heating, and chemically neutralizing—so that either a single microbe or a community of microbes could substitute for the current expensive chemical steps.

The Scientific Agenda

New biological and laboratory tools are needed to provide a detailed understanding of plant cell walls, their roles in plant function, their factors controlling resistance to break down, and their potential optimization for the eventual fermentation of sugars.

The power of modern genome sequencing and the capabilities at the DOE's Joint Genome Institute can be applied to these challenges. Using genome sequence (e.g., from switchgrass, poplar trees, etc.) to explore the genetic information encoded within will allow researchers to improve their knowledge about plant feedstocks and microbes used for conversion.

This work will involve identifying: genes involved in the synthesis of cell-wall molecules and higher structures; reactions performed by the multitude of enzymes involved; design principles of cell walls; and factors controlling the amounts, composition, and structure of polymers and polymer matrices. Discovery of new biomass-degrading biochemistries in organisms across many different kingdoms of life—including plants, fungi, and bacteria—will also expand our capabilities relevant to biomass conversion to biofuels.

*DOE's Office of Science and Office of Energy Efficiency and Renewable Energy